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IMPACT TESTS OF URETHANE FOAM

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ABSTRACT

The impact behavior of a low-density urethane foam was investigated experimentally, and the crushing characteristics of the rigid closed-cell foam were determined as a function of impact velocity, foam sample thickness, and temperature. The dynamic crushing strength of the material was found to be much better than its static strength. This energy-absorbing capability allows consideration of the foam as protection for the underbodies of Arctic surface effect vehicles (ASEV) against the impact of collisions.

ADMINISTRATIVE INFORMATION

INTRODUCTION

During high-speed operations in the Arctic regions, the Arctic SEV will pass over irregular terrain which includes sea ice, hummocks, pinnacles, and ice ridges. The variety of adverse weather conditions anticipated in such an environment could seriously limit craft capability to detect and avoid ice obstacles and thus increase the danger of serious collisions. To avoid ice obstacle collisions, the craft must be able to climb slopes and pass over ice obstacles at high speeds. Any loss of power to the lift system could cause the vehicle to descend onto an ice obstacle and the resulting impact could damage and/or penetrate the hard structure of the craft underbody.

A flotation system consisting of low-density (2 lb/ft^3) closed-cell foam has been proposed to protect the underbody area below the structural plating.[1] The primary purpose of the foam is buoyancy, and this function

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[1] Boeing Company, "Final Technical Report on Arctic SEV Program," preliminary draft (Feb 1973).

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must not be degraded by routine landings on ice or water. A secondary function of the urethane foam is energy absorption in an underbody collision protection role. Since collision is not a routine event, limited crushing of the total foam coating and therefore limited degradation of the craft buoyancy may be tolerated. The problem therefore is to determine (1) whether the foam has sufficient energy-absorbing capability to withstand a collision between an ice obstacle and a portion of the underbody area and (2) the thickness of foam required to bring the craft to rest without increasing damage to the hard structure.

METHOD

TEST PROCEDURE

The experiments consisted of a series of drop tests utilizing a 50-ft drop tower (Figure 1) with a potential drop height of 45 ft. The test samples were cut from molded blocks of foam (8 × 4 × 2 ft) and were positioned on a nonyielding surface at the foot of the drop tower. The guide cables which align the impact mass toward the foam samples restricted the sample size to a maximum of 30 × 30 in. An electrical solenoid mechanism was employed to release the impacting mass from the desired height directly above the samples. To determine the accelerations (decelerations) along the line of impact, two accelerometers were positioned on the impacting mass. Duplication was practiced to avoid loss of data and to increase the accuracy of the system. Since the impacting mass is free falling, the vertical acceleration due to gravity will act along the same line as the crushing forces. To account for this motion, a datum was established, namely, the value measured by the accelerometer just prior to impact. Data from the accelerometers were amplified and recorded on magnetic tape and later displayed on an oscillograph.

To determine the effects of low temperatures during impact testing, a freezer was used to bring the sample down to about -10 F. The freezer compartments were capable of holding a maximum of one 24- × 24- × 12-in. sample or two 24- × 24- × 6-in. samples at any given time. The test samples were retrieved approximately every 48 hr and were ready to test within 5 min. Since the thermal conductivity was very low (indicative of an excellent
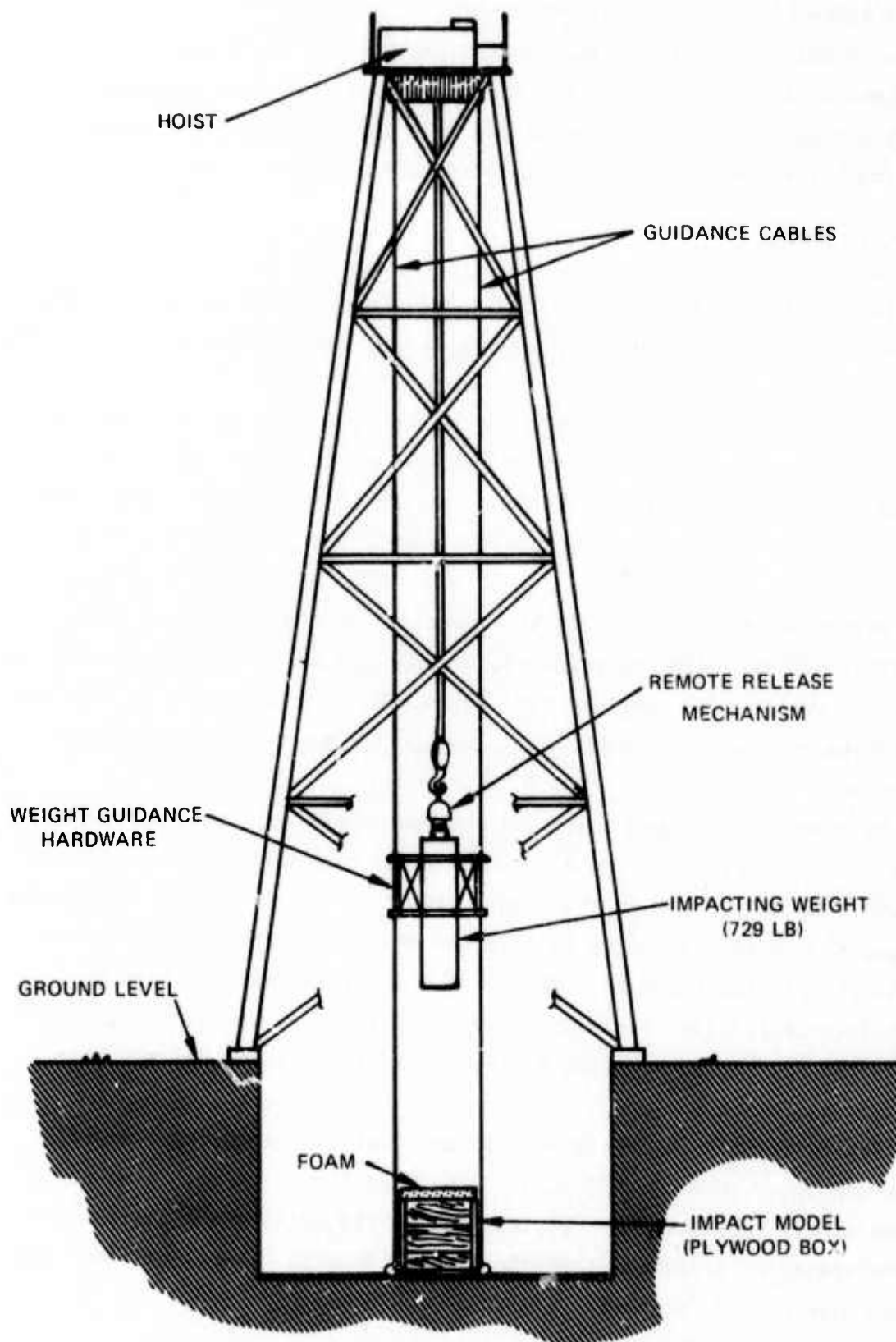
Figure 1 - NSRDC Drop Test Tower Facility

insulator), it was felt that the change in temperature that resulted from the cold condition would be insignificant.

A thermometer recorded the temperature within the freezer compartments when the sample was ready for testing. No temperature readings in the sample were attempted because it was felt that surface penetration would affect the energy-absorbing characteristics of the foam.

MATERIAL BEHAVIOR

In discussing the dynamic loading and energy-absorbing capabilities of low-density urethane foam, it is worth noting briefly the manner in which the material physically behaves under an impacting load.

Urethane foam is classified as a closed-cell material that contains many microscopic bubbles of Fluorocarbon blown rigid foam. In its natural form and under a zero loading condition, gas is encapsulated within a cell structure that is hexagonal in form when viewed at a 25X magnification (Figure 2).

When crushing initiates in the impact area under a dynamic load, the cell structure begins to collapse, thereby releasing gas. Since the load causes further deformation, cell collapse is considered to be progressive in nature. Figure 3 shows cell structures that have collapsed and taken on an oblong shape.

As a sample crushes, energy is absorbed until the mass is brought to rest. Before the impacting mass velocity is reduced to zero, bottoming may occur, for example, when the sample cannot absorb all of the energy and the rigid foundation is forced to halt the mass rather than simply provide support for the crushing foam. The force history is characterized by a more or less rapid rise to a higher force. This force is bottoming, and it is delivered not by the crushing sample but by the response of the "non-yielding" foundation.

The interesting behavior of this material occurs during transition from an uncrushed to a crushed state. The transformation to a crushed state so alters the material that it takes on the resilient qualities and the consistency of a sponge; thus the crushed foam is capable of absorbing water because of cell collapse.
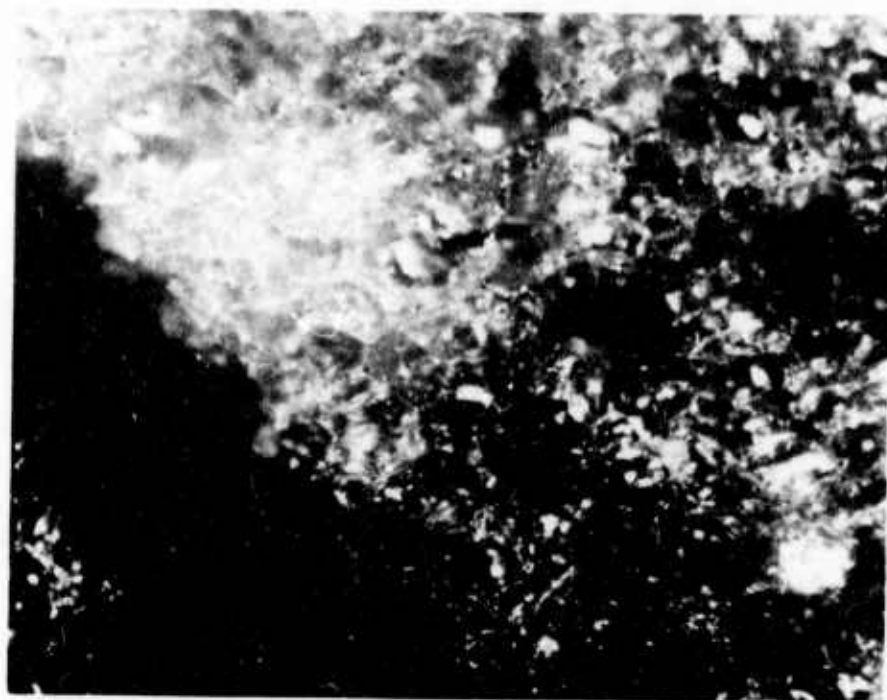
4

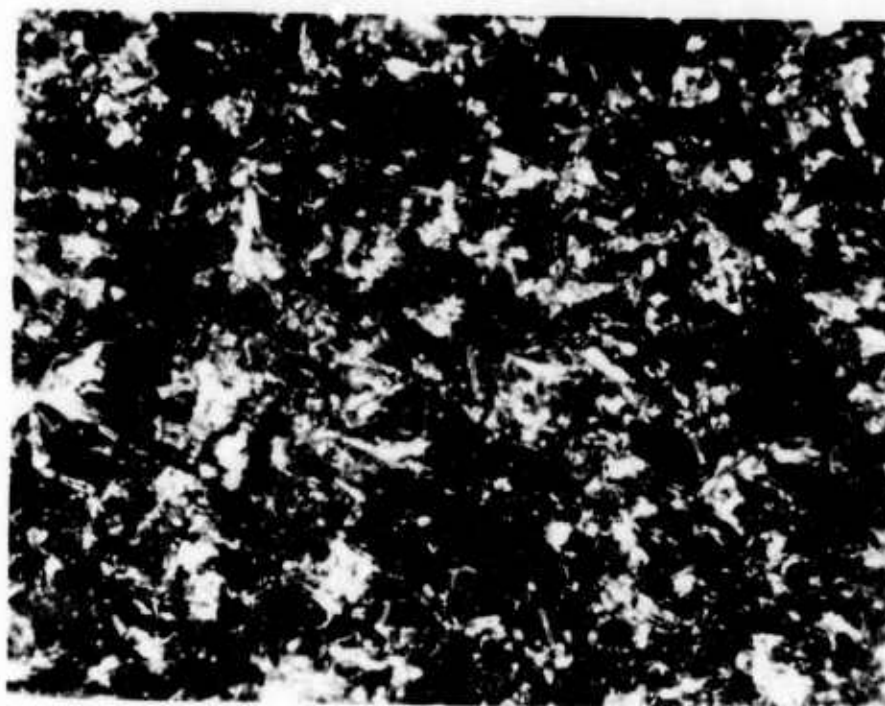Figure 2 - Magnified (25X) Cell Structure of Uncrushed Sample

Figure 3 - Magnified (25X) Cell Structure of Crushed Sample

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To verify this fact, a simple water-absorption test was performed on two samples of identical volume, one uncrushed and one which clearly displayed resilient qualities. Both samples were placed under a 12-in. head of water and periodic recordings were made of the weight of water absorbed (Figure 4). The maximum water absorbed by the crushed sample represented 38.71 percent of its volume after 700 hr and 8.13 times its weight. The uncrushed sample absorbed a maximum of 2.9 percent of its volume in 50 hr or only 0.88 times its own weight. It is interesting to note that the density of the crushed sample was 3 lb/ft^3 and that of the uncrushed sample 2 lb/ft^3. It should be pointed out that the crushed sample was extremely susceptible to damage as a result of this water absorption; careful handling was necessary to avoid loss of any fragmentary pieces of foam.

In order to present meaningful data on the dynamic loading and energy-absorbing capabilities of the foam, particular attention was focused on the manner in which to subject a sample to an impact loading condition. During preliminary tests, a selected sample was cut from a molded block of foam, placed on a nonyielding surface under the impact mass, and the mass was released from a predetermined drop height. As contact was made, the sides of the sample surrounding the impact area were thrown in an outward direction, leaving only a center core of foam intact under the impact mass (Figure 5). These results revealed that the foam was not sufficiently contained. Therefore, an attempt was made to model the rigidity and containment influence of the rest of the foam in an infinite layer of foam. This was done by physically containing the sample in a plywood box banded with steel straps (Figure 1).

Several samples were also tested with coatings of 0.060-in. fiberglass laminate fabric No. 164 and 0.063-in. sheet aluminum 6061-T6. A commercial epon-epoxy was used to bond individual coatings to the exposed top surface of a sample. Impact tests on the coated samples were conducted in the same manner as the uncoated samples.
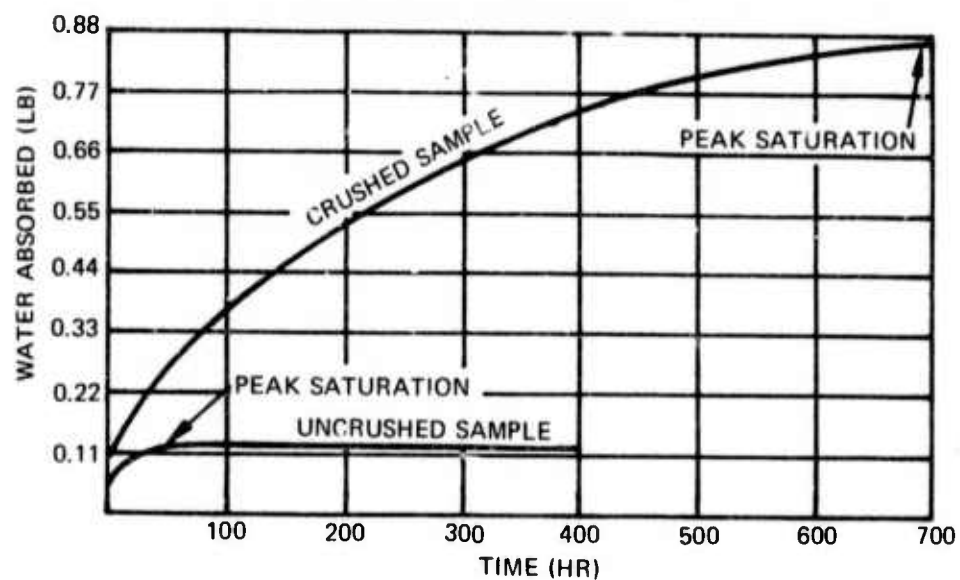
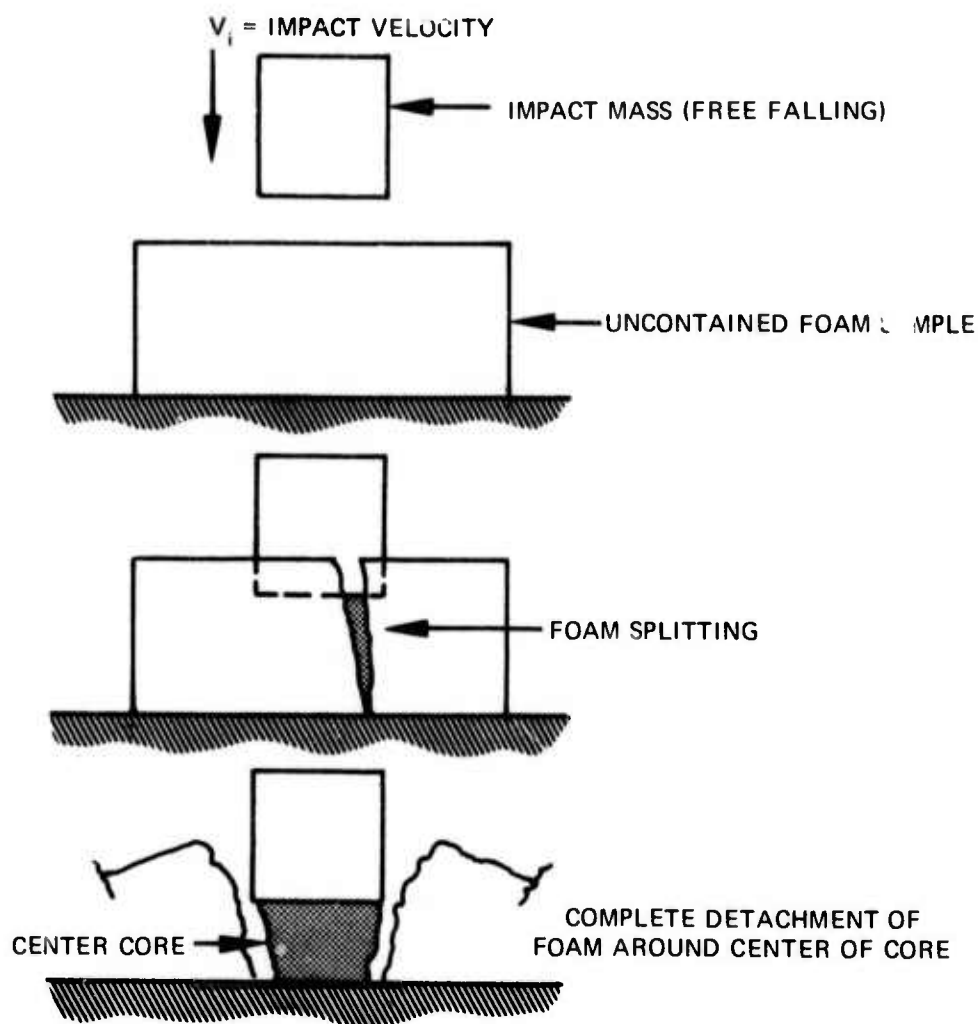Figure 4 - Water Absorption of Crushed and Uncrushed Samples

Figure 5 - Dynamic Loading Sequence for a Physically Uncontained Sample

RESULTS AND DISCUSSION

ACCELERATION-TIME HISTORIES

Figure 6 presents test records in the form of acceleration-time histories for a typical test series at incremental velocities. The records typically showed a linear rise to a constant acceleration level. This constant level was maintained for relatively long times and thus a linear decay to zero acceleration occurred. In the event of bottoming, the linear decay to zero acceleration was replaced by a nonlinear, sudden rise to much higher acceleration values, followed by a rapid decay to zero acceleration.

In order to evaluate the dynamic loading characteristics and energy-absorption capabilities of the foam, two parameters were taken directly from the acceleration-time histories, the effective time duration T_{eff} and the acceleration a measured in g units. It should be noted that T_{eff} was measured before bottoming occurred.

As impact initiates, the acceleration undergoes a rapid increase until a constant level is achieved. If the sample thickness is sufficient, the impacting mass will come to rest without bottoming (Figures 6a and 6b); if it is insufficient, bottoming will occur (Figures 6c and 6d).

DYNAMIC CRUSHING PRESSURE P_{cr}

The acceleration-time histories indicated that as the impact head contacted the foam, the force level increased until it reached a constant level. The pressures exerted by the foam is termed the dynamic crushing pressure. It is the product of the weight of the impact mass and the acceleration divided by the impact area. Figure 7 is a plot of the dynamic crushing pressure versus impact velocity for two series of ambient temperature samples. These results indicate that the dynamic crushing pressure is a function of impact velocity and sample thickness. This velocity effect is probably due to the fact that the entrapped gas must escape in order for the foam to fully collapse. This is possible under static loading; however, the entrapped gas cannot escape fast enough under dynamic loading and therefore the force levels rise.

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The dynamic effects display a higher stress level than the static compressive stress level of 20 psi. This, of course, is advantageous when designing the foam for dynamic loading. (The value of 20 psi was taken from a technical info mation chart.[2] Verification was attempted by testing a sample under static compression. Results revealed a yield stress level of 22.2 psi as taken from a stress-strain curve in Figure 8. Also, a cold sample test revealed an 18.6-psi compressive yield stress; see Figure 9.)

The effects of temperature on the dynamic crushing pressure were determined by comparing at ambient and cold temperatures (about 10 F) samples of identical size and thickness at identical impact velocities. Figure 10 shows the temperature effect on 24- × 24- × 12-in. samples. These results indicate a definite reduction of from 12 to 25 percent in dynamic crushing pressure P_{cr} depending on the impact velocity V_i. This reduction is considered attributable to the more brittle nature of the foam at low temperatures.

Figure 11 illustrates the effect of impact velocity on the dynamic crushing pressure of the 30- × 30-in. sample at ambient temperatures. Note that the crushing pressure did not vary significantly with impact velocity above a velocity of about 10 ft/sec. Figure 12 shows the effect of sample thickness on the dynamic crushing pressures for the same samples.

It should be pointed out that throughout these tests, the approximation to an infinite layer of foam was not achieved. In other words, the size relationship of the impact area to the total area of the sample was important enough to affect the force levels. This is indicated in Figure 11 where the expected curve for the 30- × 30- × 12-in. sample would be expected to lie well below the actual curve of a 24- × 24- × 12-in. sample. This indicates that the effect of an increase in sample size is to decrease the dynamic crushing pressure P_{cr} for the incremental impact velocities. Therefore, for large size samples, P_{cr} will be expected to decrease until

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[2]"Technical Information Chart," Upjohn Company, Torrance, California (Jan 1967).
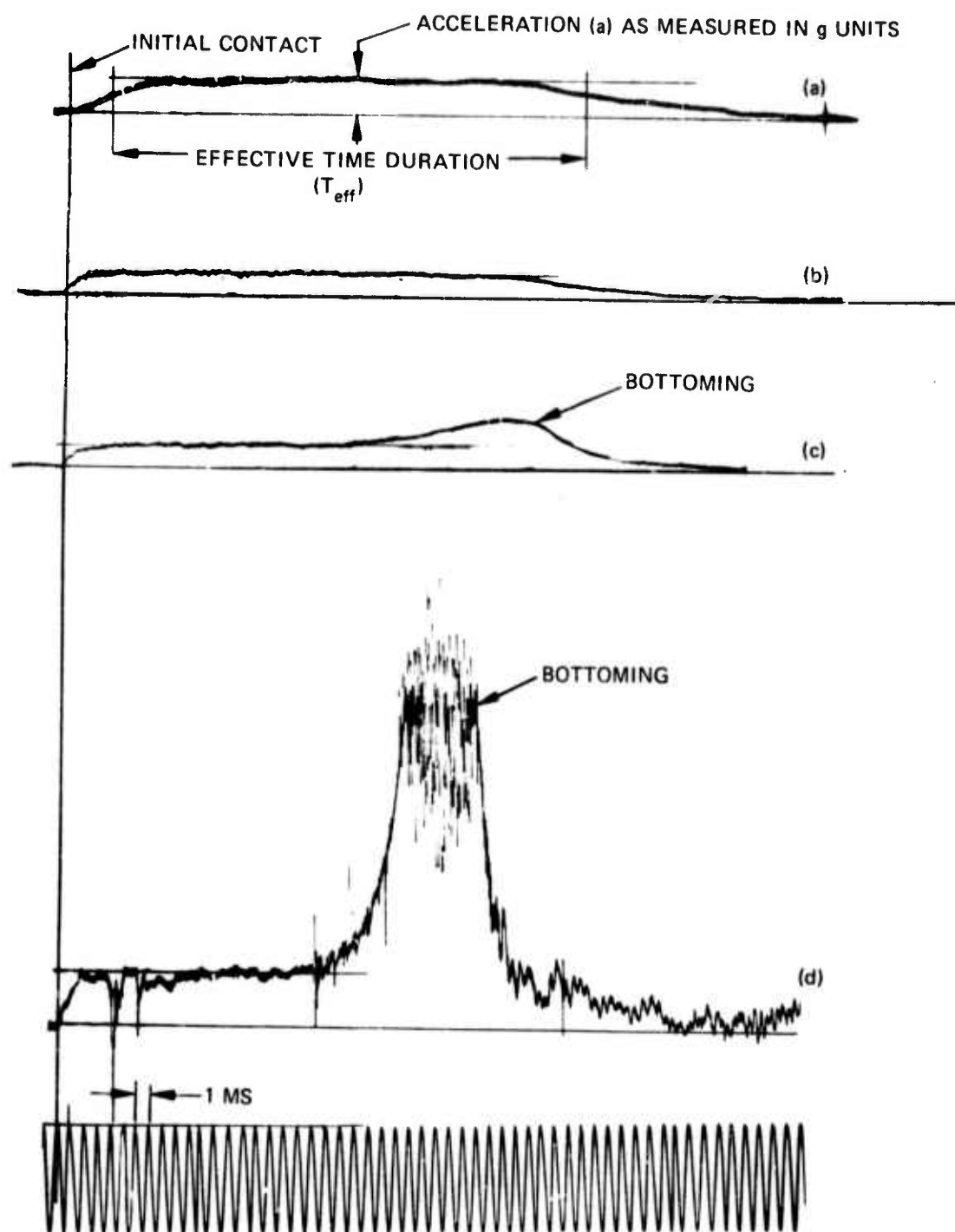
Figure 6 - Typical Acceleration-Time Histories for Ambient Samples
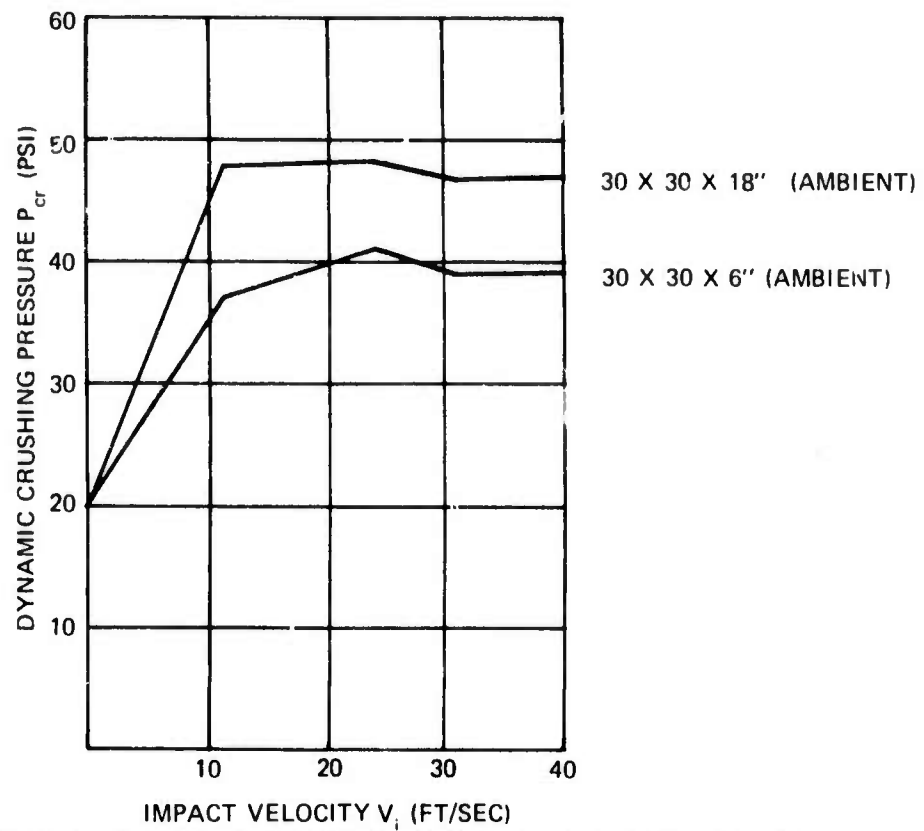
Figure 7 - Dynamic Crushing Pressure versus Impact Velocity as a
Function of Thickness
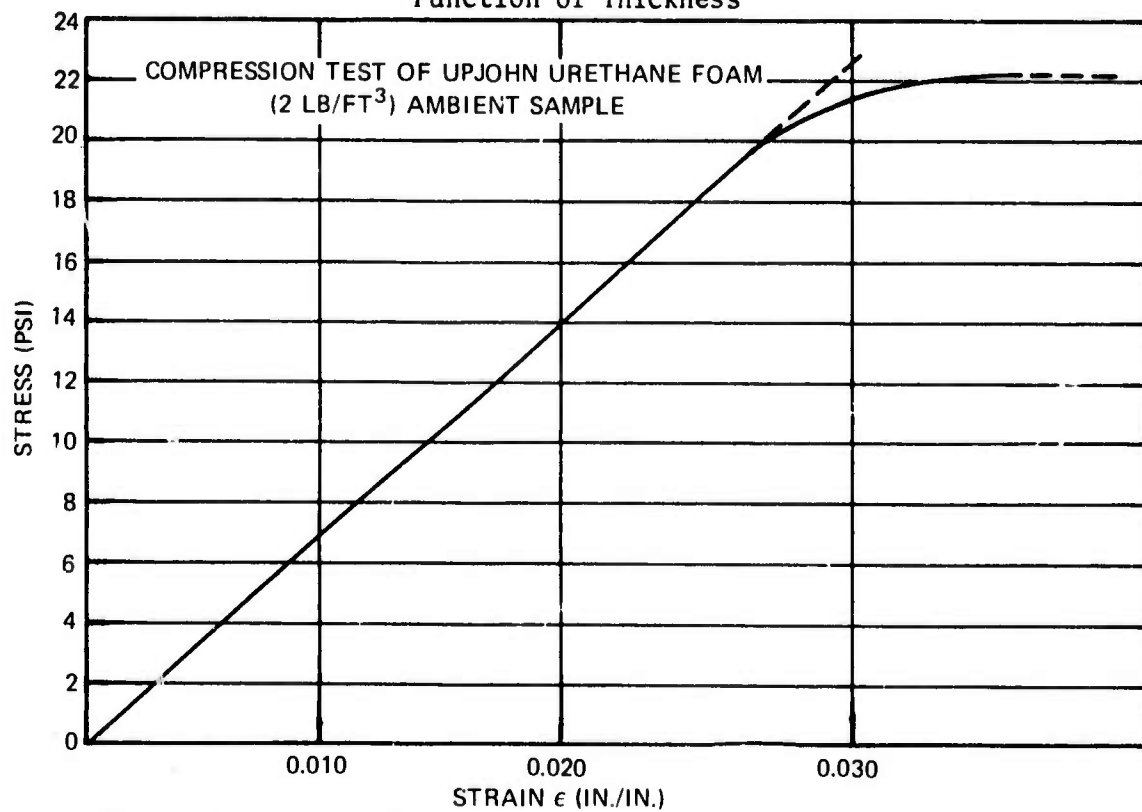
Figure 8 - Stress-Strain Curve for Ambient Temperature Sample

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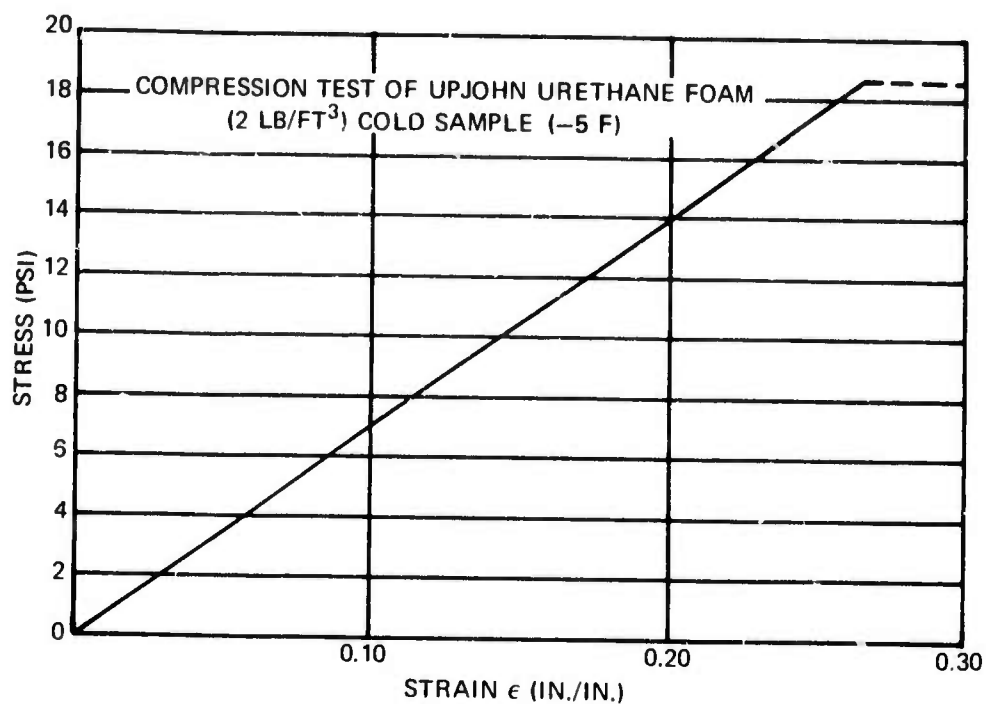
Figure 9 - Stress-Strain Curve for a Cold Sample

Figure 10 - Dynamic Crushing Pressure versus Impact Velocity as a
Function of Temperature

24 x 24 x 12" (TESTED)

30 x 30 x 18" (TESTED)

30 x 30 x 12" (EXPECTED RANGE—NOT TESTED)

30 x 30 x 6" (TESTED)

Figure 11 - Dynamic Crushing Pressure versus Impact Velocity as a
Function of Sample Size

Figure 12 - Dynamic Crushing Pressure versus Foam Thickness as a
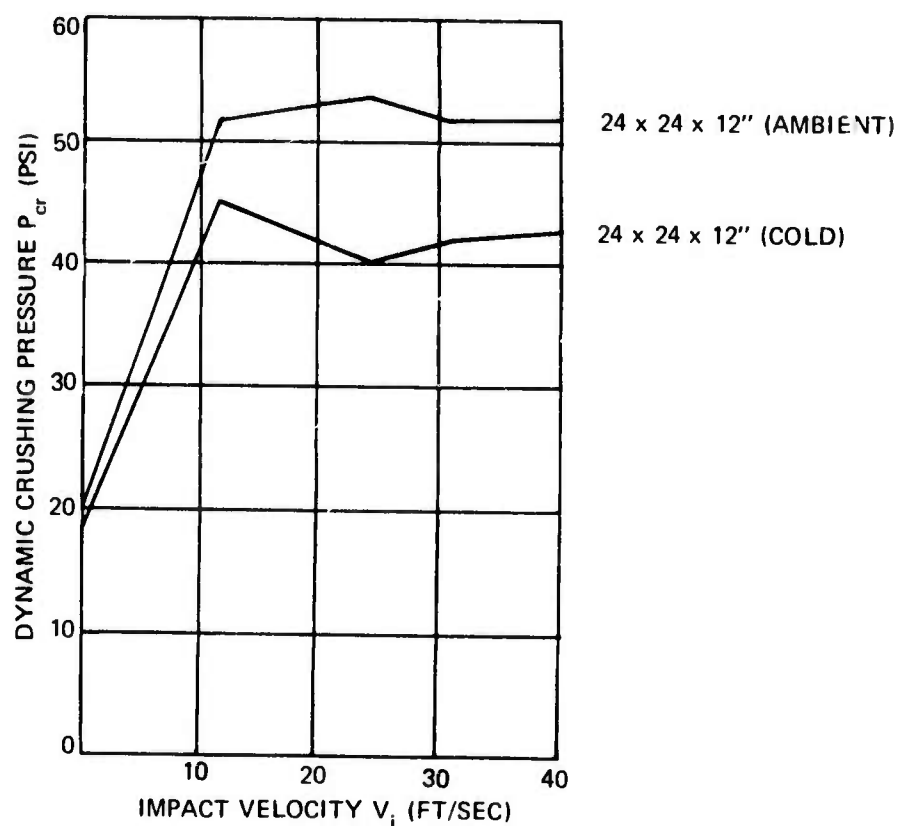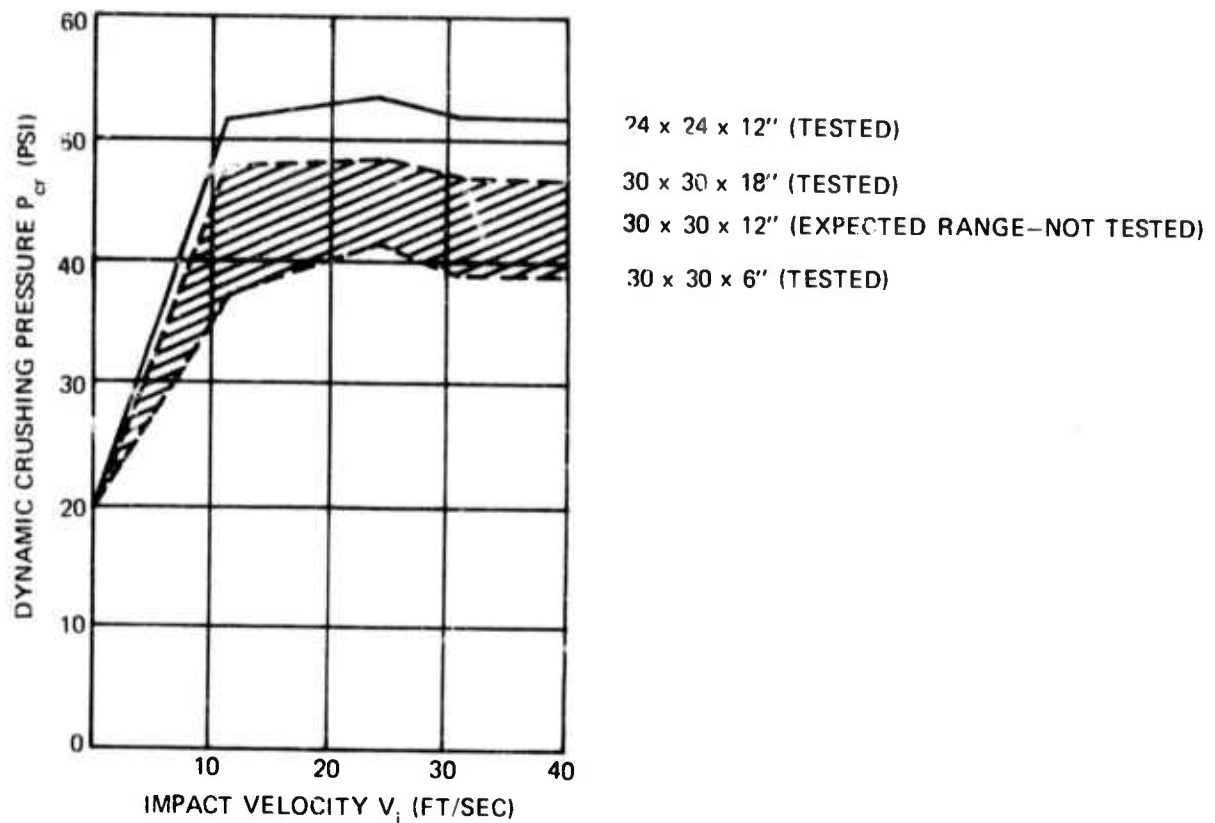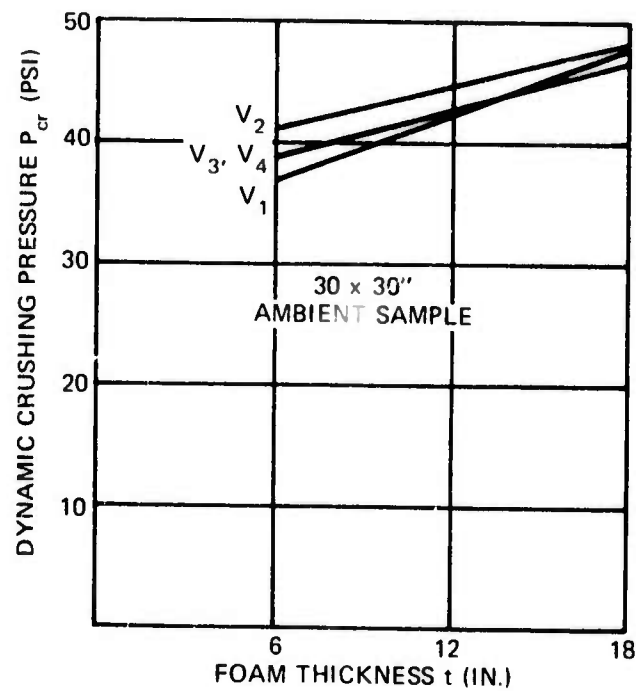Function of Impact Velocity

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an infinite sample size is approximated. Although it is recognized that
an infinite layer of foam was not achieved, the data may be used for com-
parative studies of velocity and thickness and as an upper bound on actual
impact loads.

It is interesting to point out that under an impact load as described
earlier, the behavior of a physically uncontained sample showed a consider-
able reduction in force levels compared to those of a physically contained
sample. This was evident from the acceleration-time histories (Figure 13);
the force levels for the physically uncontained sample were equal to
approximately 25 percent of the physically contained sample. It is felt
that an infinite layer of foam can be approximated by containing the samples
more closely.

ENERGY ABSORPTION

The amount of energy that a body can absorb depends on the internal
work of that body. Work, of course, is produced by a force acting through
a distance. When a load is applied to the foam, work is done on the foam
and energy is absorbed by the foam. During dynamic loading, the impact
mass possesses kinetic energy by virtue of the fact that it is a body in
motion. It will do a certain amount of work against a resistant force,
namely, the foam crushing pressures, before it comes to rest. Since the
impact mass loses speed, there is a loss in kinetic energy which is equal
to the product of the retarding force (a product of the impacting weight
and the acceleration) and the distance traveled in the foam. These
deformations can be expected to increase as the impact velocity is increased.
If a constant deceleration rate is assumed, deformation can be calculated
from the basic equation of motion:

$$y = V_i \ (T_{eff}) + \frac{1}{2} \ a(T_{eff})^2 \tag{1}$$

where   y is the distance through which the impact load has traveled,

V_i is the impact velocity as determined from the drop heights,

T_{eff} is the effective time duration obtained from the acceleration
and time history records, and

a is the acceleration due to crushing foam.

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UNCONTAINED
24 x 24 x 12" AMBIENT SAMPLE
V_3 = 31.08 FT/SEC
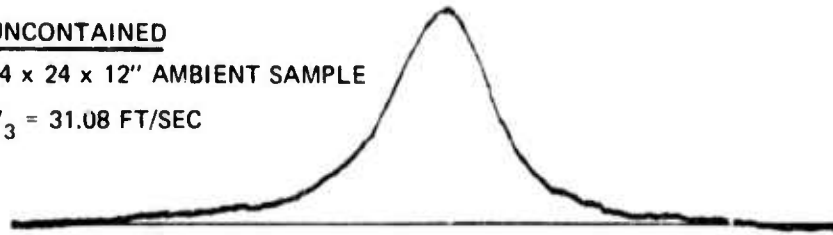
CONTAINED
24 x 24 x 12" AMBIENT SAMPLE
V_3 = 31.08 FT/SEC
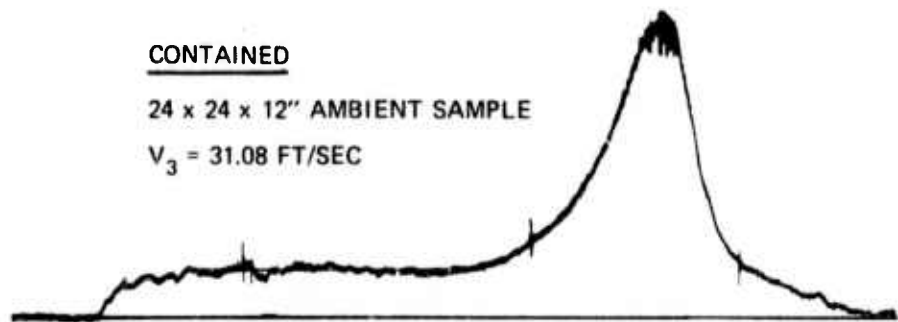
1 MSEC
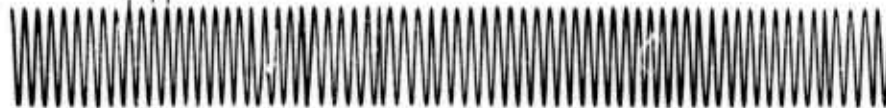
Figure 13 - Acceleration-Time Histories Illustrating the Effect
of Containment

The foam has a limited amount of energy-absorbing capacity, and if the kinetic energy of the impact condition is higher than the capacity of the foam to absorb it, the additional energy must be absorbed in other ways--this is bottoming. The energy is absorbed in the elastic deformation of the foundation structure. Since the foundation in the test facility is much stiffer than the samples, much higher accelerations (decelerations) result.

It is interesting to note that once the load (impact mass) was removed from the sample following the test, the foam recovered a small fraction of the deformation. This is an indication of the elastic phase of the energy-absorbing process. Measurements on a selected series of samples taken before and after the tests indicated that foam recovery in the area of impact was approximately 10 percent of the total deformation (Figure 14).

It was felt that only the bottomed samples should be used in calculating maximum energy absorption to ensure that all the energy in the foam was completely dissipated. Since some samples did not bottom, it was necessary to scale up the deformations to the depth at which bottoming would occur. This was accomplished by averaging the ratios of the calculated deformations y to the original sample thickness t for the bottom samples. Calculations were based on the 30- × 30-in. and 24- × 24-in. test series for ambient samples. The cold samples were averaged separately. The results revealed ratios of 0.76 and 0.80 for ambient and cold samples, respectively.

Figure 15 is a plot of maximum energy absorption versus sample thickness for ambient and cold samples as a function of impact velocity. Note that the foam displayed no significant change in the average maximum energy levels as a result of temperature. However, it should be pointed out that these cold temperatures had effectively reduced the dynamic crushing pressure as compared to the ambient samples, causing successive increases in the deformations as shown in Figure 10. This was the result of a corresponding decrease in the acceleration for the cold samples as recorded from acceleration-time histories
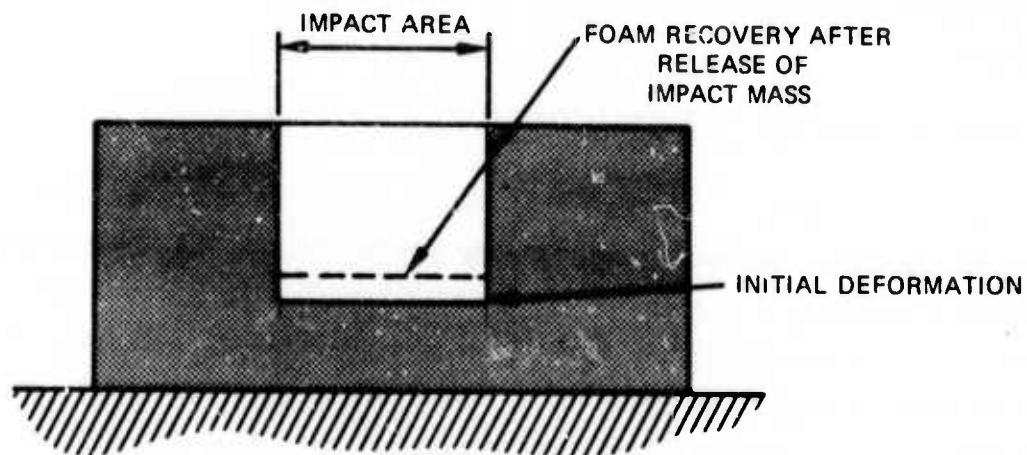
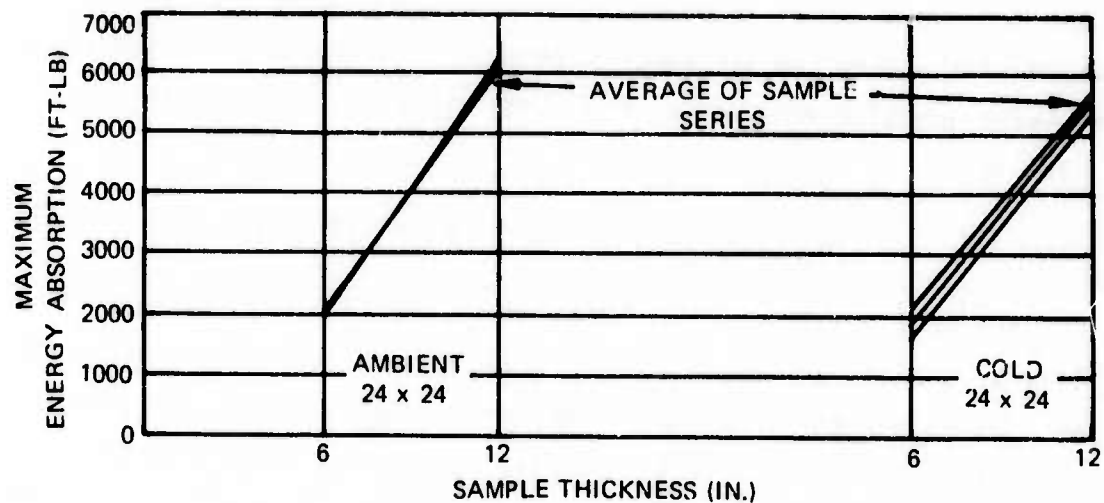Figure 14 - Foam Recovery Deformation

Figure 15 - Maximum Energy Absorption versus Sample Thickness as a Function of Impact Velocity for Ambient and Cold Samples

The 30- × 30-in. samples were used for a comparative study on velocity and thickness, as previously discussed. The maximum energy levels for these samples were calculated and plotted versus sample thickness; see Figure 16.

EVALUATION OF COATINGS

Up to this point, all test results are based on uncoated, physically contained samples. The acceleration-time histories for the coated samples indicated a somewhat different dynamic crush pressure pulse configuration in that the coatings caused an initial peak acceleration (see Figure 17) after initial contact. At relatively low impact velocities (11.35 and 24.07 ft/sec), the coatings began to debond radially from the center of the impact area to the edge of the sample. On the other hand, for higher velocities (31.07 and 41.7 ft/sec), the impact mass sheared through the coatings with an accompanying debonding. Unfortunately, the acceleration-time histories for the coated samples were inconsistent in the pulse configuration. This pulse shape probably depends on the bonding strength of the coating to the foam and the shear strength of the foam. Thus these data are useful qualitatively rather than quantitatively to indicate the effect of coatings.

PRACTICAL APPLICATIONS FOR 150-TON ASEV

The test results indicate that contained foam samples have the ability to sustain an impact loading condition by absorbing energy. The tests also show that the dynamic load-carrying capacity of the foam is a function of the thickness of the sample, the impact velocity, and the temperature. To relate this experimental evidence to practical applications, the data were used to determine the degree of protection the foam can offer in the area of the underbody for a proposed 150-ton ASEV. Specifically, does this material possess sufficient energy-absorbing capability to sustain local impacts to which such a craft might be subjected?
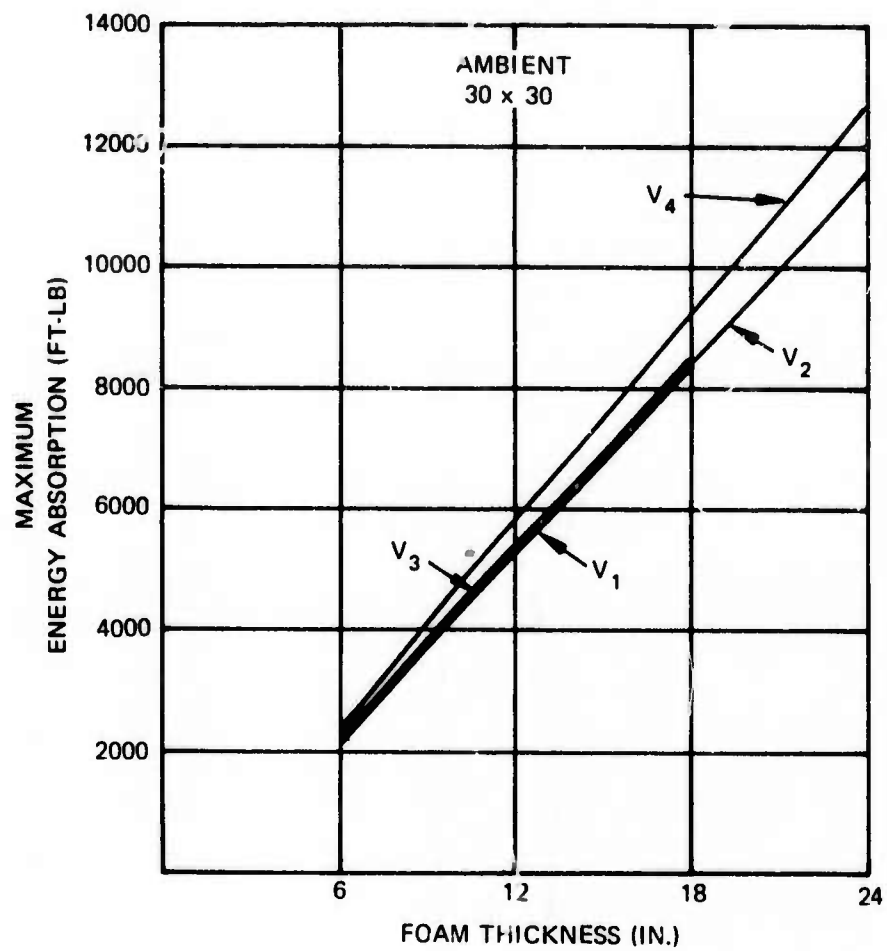
18

Figure 16 - Maximum Energy Absorption versus Sample Thickness as a Function of Impact Velocity for Ambient Temperature Samples
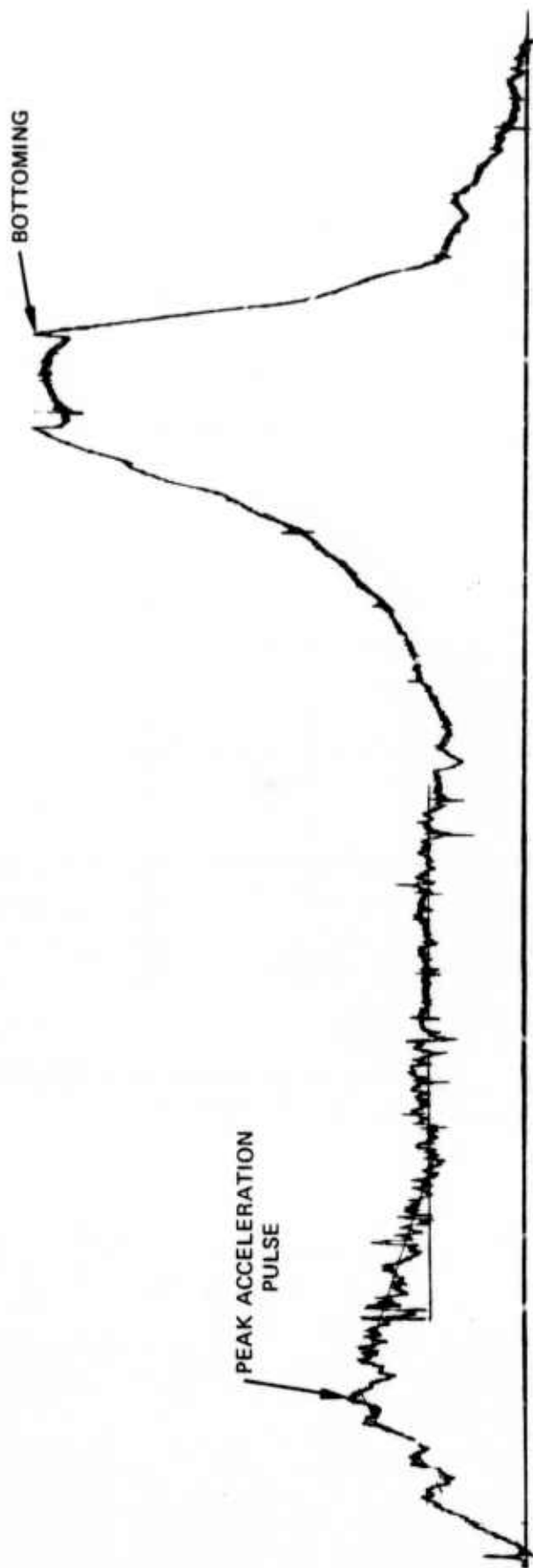
Figure 17 - Selected Acceleration-Time History for Coated Sample

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UNDERBODY COLLISION

During operations within the Arctic environment, some measure of protection must be provided to sustain a craft against possible underbody collision. Underbody collision could occur as a result of vertical motion of the craft onto an ice obstacle. This could happen as a result of accidental loss of power or it could be due to "ski jumping" an ice slope and descending onto an obstacle (Figure 18). If the craft has sufficient forward and vertical velocity at this point, a collision that ruptures an area of the underbody could result and seriously curtail further operations. It is also possible that this damage could render the craft inoperable.

The task, therefore, is to develop a system capable of absorbing the vertical kinetic energy of the ASEV. Equation (2) relates the kinetic energy E_c to the mass of the craft M and the vertical impact velocity V_i.

$$E_c = \frac{1}{2} (M) (V_i)^2 \tag{2}$$

The energy to be dissipated in underbody collision, then, is a function of the vertical impact velocity of the craft on an ice obstacle. Because ice obstacles are brittle in nature, they can be expected to absorb very little energy.[3] The kinetic energy of the craft toward the obstacle must then be entirely dissipated by the protection system, that is, the protection system must be relied on to bring to zero the craft velocity in the direction of the obstacle. If this is not accomplished, damage to the craft is inevitable. The degree of protection that this material has to offer then becomes important. It is a function of the amount of energy absorbed in a given impact configuration.

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[3]Pounder, E. R., "Physics of Sea Ice," Pergamon Press, New York (1965).

VELOCITY COMPONENT ALONG THE CRAFT

VELOCITY COMPONENT V toward the obstacle
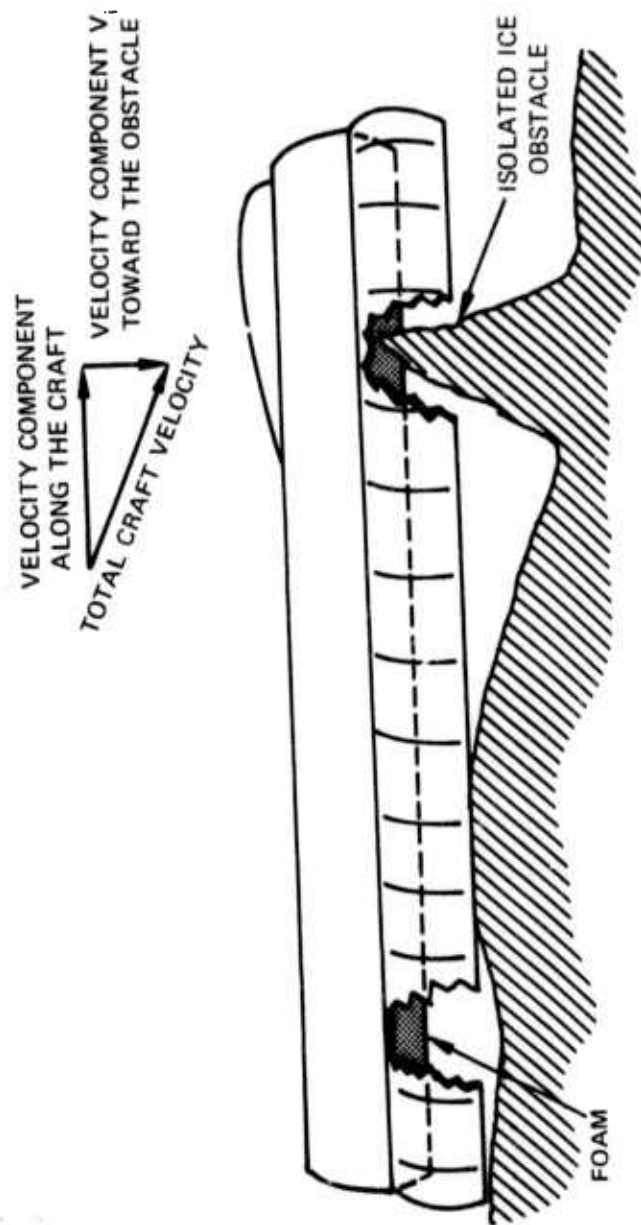
TOTAL CRAFT VELOCITY

ISOLATED ICE OBSTACLE

FOAM

Figure 18 - "Ski Jumping" an Ice Obstacle

DEGREE OF PROTECTION

Allowable impact velocity is estimated by equating the kinetic energy of the craft E_c in the vertical direction to the energy-absorbing capabilities of the foam E_f based on experimental results as shown below.

Kinetic Energy of Craft = Energy of Foam

$$E_c = \frac{1}{2} MV_i^2 = E_f = P_{cr}A(K)t$$

Therefore:

$$V_i = \left[\frac{P_{cr}A(K)t}{(0.5M)} \right]^{1/2} \tag{3}$$

where V_i is the allowable impact velocity of the craft in the direction of the obstacle,

P_{cr} is the experimental dynamic crushing pressure,

A is the impact loaded area,

K is the "effective thickness ratio" (i.e., the ratio of the maximum foam deformation caused by a dynamic load without bottoming to its original thickness t),

t is the original thickness of the foam, and

M is the mass of the craft.

It should be made clear that before V_i can be determined, careful consideration should be given to choosing a suitable dynamic crushing pressure. This is so because P_{cr} is a function of several variables: thickness t, impact velocity V_i, and temperature. The value of P_{cr} = 52 psi used here corresponds to a 12-in. thickness of foam under ambient conditions. Also, the effective thickness ratio K represents an average effective thickness for the test data and was chosen equal to 0.76t. It varies with thickness t, impact velocity V_i, and temperature, and should be chosen with care for specific problems.

Calculations were made from Equation (3) and plotted in Figure 19a to illustrate the protection required for a 150-ton craft as a function of impact velocity and impact area. This plot relates the thickness of

protection required versus allowable impact velocity for a range of percentages of underbody area involvement.

These results show that for a reasonable impact area (3 percent of underbody area), the craft could be brought to rest without bottoming with an allowable impact velocity of 17 ft/sec or a free-fall drop from 4.55 ft for a 2.5-ft thickness of foam. If V_i is greater than 17 ft/sec, the impact load would be transmitted to the hard structure and cause damage. For an extreme case where the total underbody is involved such as in landing operations on smooth ice, a 2.5-ft thickness of foam could sustain a vertical impact of 99 ft/sec or a free-fall drop of 152 ft before bottoming results. This is well above any impact velocity that the craft is expected to experience. The underbody structure must, of course, be designed to withstand the dynamic crushing pressure of the foam.

Craft mass must be taken into account in order to extend this information to different size craft: a more massive craft moving at the same velocity as a smaller craft has proportionally more kinetic energy. Figures 19b and 19c illustrate the effect of larger craft mass on the allowable impact velocity for a range of obstacle sizes. It can be seen that very large thicknesses are needed to absorb the energy in the heavy craft. These figures also show the rigid body accelerations which the impact forces would cause if the impact were symmetric about the plane location of the vehicle center of gravity. If the vertical impact occurs elsewhere on the craft underbody, higher acceleration may occur. In order to determine the magnitude of these accelerations, the mass distribution of the craft must be known.

Available information[4] indicates that vertical accelerations of about 10 g begin to cause crew injury. An obstacle of about 400 ft^2 is sufficient to cause this acceleration level for the 150-ton craft. On the 800-ton craft, an obstacle of about 2140 ft^2 is necessary to cause the same 10-g acceleration. Note that under high impact velocities, mechanical shock damage may also occur at these acceleration levels.

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[4] "Materials Selector Issue of Materials Engineering," Reinhold Publishing Corp., Stamford, Conn., Vol. 72, No. 6 (Nov 1970).

Figure 19 - Foam Thickness Necessary to Sustain Various Vertical Impact
Velocities without Bottoming as a Function of Underbody Area Contact

150-TON CRAFT

ALLOWABLE IMPACT VELOCITY V_{i_a} (FT/SEC)/FREE-FALL DROP HEIGHT (FT)

Figure 19a - 3-, 50-, and 100-Percent Underbody Involvement

150- TO 800 CRAFT

16 FT² AREA	160 FT² AREA
0.5% OF 150 TON	5.0% OF 150 TON
UNDERBODY AREA	UNDERBODY AREA

ALLOWABLE IMPACT VELOCITY V_{i_a} (FT/SEC)/FREE-FALL DROP HEIGHT (FT)

Figure 19b - 0.5- and 5-Percent Underbody Involvement

25

Figure 19 (Continued)

150- TO 800-TON CRAFT
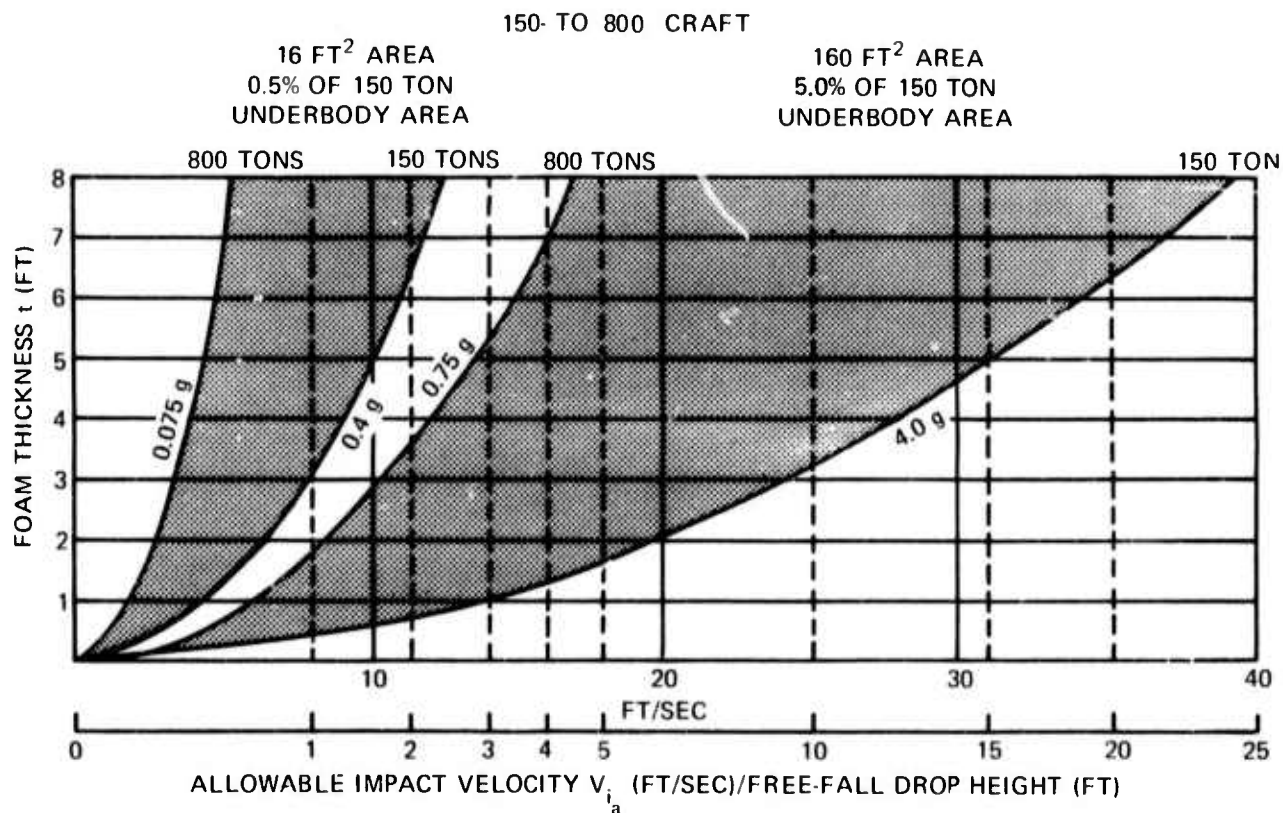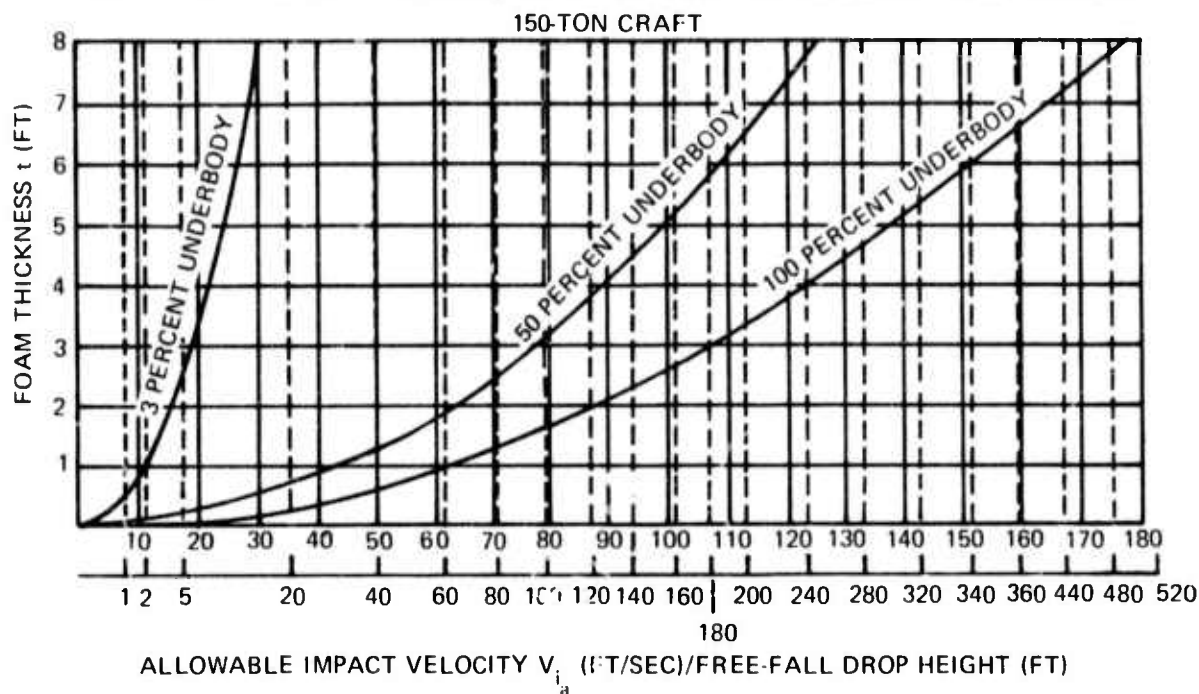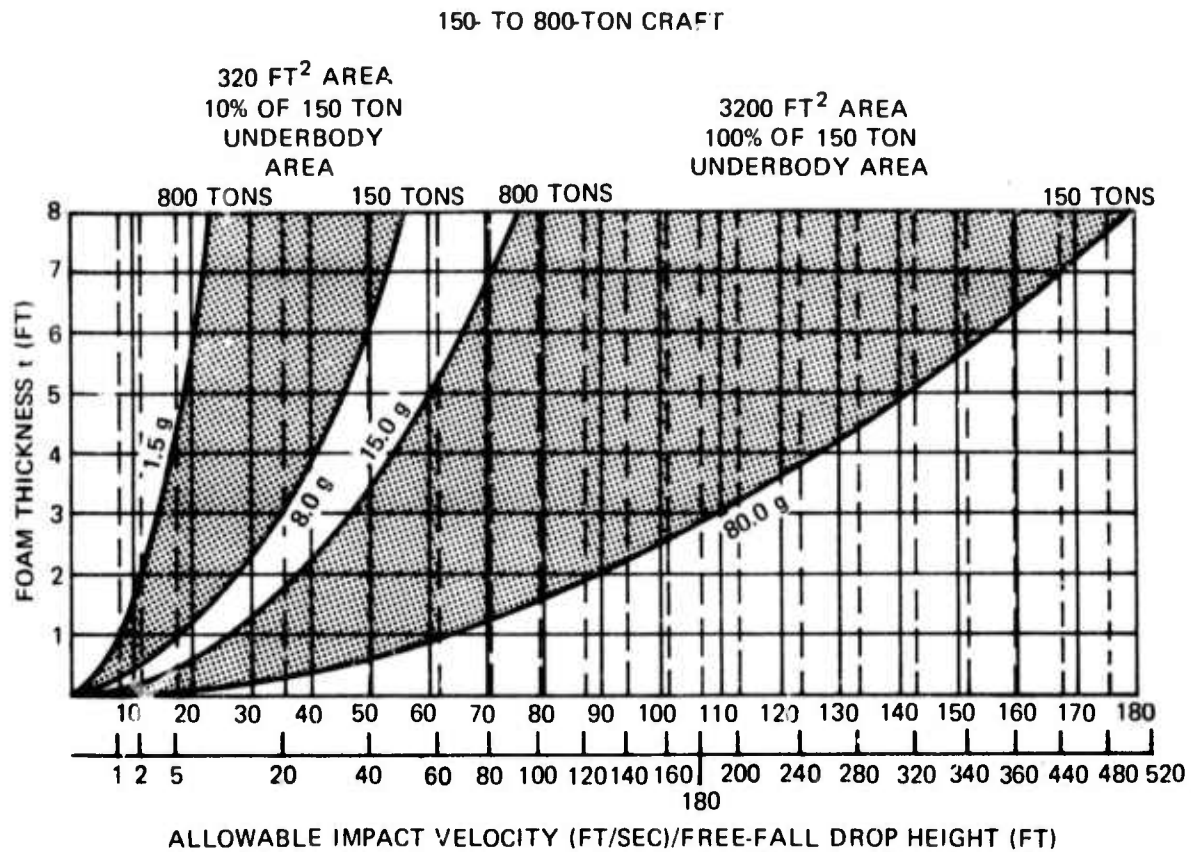

Figure 19c - 10- and 100-Percent Underbody Involvement

These results were all based on experimental data for tests at ambient temperature but they are considered applicable also to subzero temperatures in the Arctic environment. It can be shown that for the thickness range investigated, the energy-absorbing capability of the foam is practically independent of temperature even though the effective thickness ratio and the dynamic crushing pressure are both somewhat dependent on temperature. The comparison of the two test series at ambient and cold temperatures (Figure 15) revealed only a small influence of temperature on the absorbed energy.

Up to this point, we have considered only the action of vertical kinetic energy on the craft center of gravity. If during a collision it takes more than a small dent to bring the craft to rest, the obstacle will impact on the side wall of the dent and the horizontal impact velocity toward the obstacle (Figure 18) must also be considered. Even though a relatively small thickness of foam can sustain relatively high drop heights for impacts in the vertical direction, the situation will become very undesirable if horizontal kinetic energy is also involved. The velocity component along the craft is usually much greater than the vertical velocity component[5] (Figure 18), and the obstacle will tend to rip through the foam.

Based on experimental results and the assumptions stated, it is considered that a reasonable thickness of urethane foam can absorb the vertical kinetic energy of a 150-ton craft; however, significant increases in required foam thickness are necessary for use on a larger craft (see Figures 19b and 19c). In the case of impacts on a large area of the craft underbody, the energy-absorbing capability of the foam is good. However, for impacts on small surface areas (such as impact with ice pinnacles), the energy-absorbing capability of the foam is poor and underbody damage may be expected.

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[5]Gilbert, W. E., "Collision Protection for the Arctic Surface Effect Vehicle," NSRDC Report 3885 (Feb 1973).

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WATER ABSORPTION FOR CRUSHED SELECTIONS OF FOAM

Figure 4 shows the ability of a crushed sample of foam to absorb water. If this occurs in the actual craft, the additional weight may create a problem. Useful data from the previous discussion on water absorption can now be used to evaluate a crushed section of foam subjected to water contact. If the material density is assumed to remain the same regardless of the amount of foam (i.e., the number of cells per unit volume is the same), then a simple proportion can be written as:

$$\frac{W_w}{W_s} = \frac{W_w^*}{W_s^*} \tag{4}$$

where W_s is the weight of crushed foam as taken from a test sample,

W_w is the weight of water that is absorbed by a test sample at any given time,

W_s^* is the weight of the particular crushed foam, and

W_w^* is the weight of water absorbed for the particular crushed section.

To solve for the weight of water absorbed by a section of foam on an actual craft, Equation (4) may be written as follows:

$$W_w^* = \frac{W_w}{W_s} W_s^* \tag{5}$$

Figure 20 presents an estimate of the number of tons of water which will be absorbed by the foam as a function of time for various percentages of underbody involvement. The foam is assumed to be 2.5 ft thick and fully crushed in the impact zone. Note that the larger the contact area, the higher the impact velocity needed to achieve a fully crushed condition and maximum water absorption (Figure 21). Indications are (Figure 20) that locally crushed sections of foam subjected to prolonged submergence do not appreciably affect the craft total weight. For large areas of underbody collision involvement, however, the weight of water absorbed is significant. If the foam is allowed to remain submerged for 1 day, corresponding crushed sections that represent 3, 50, and 100 percent of underbody
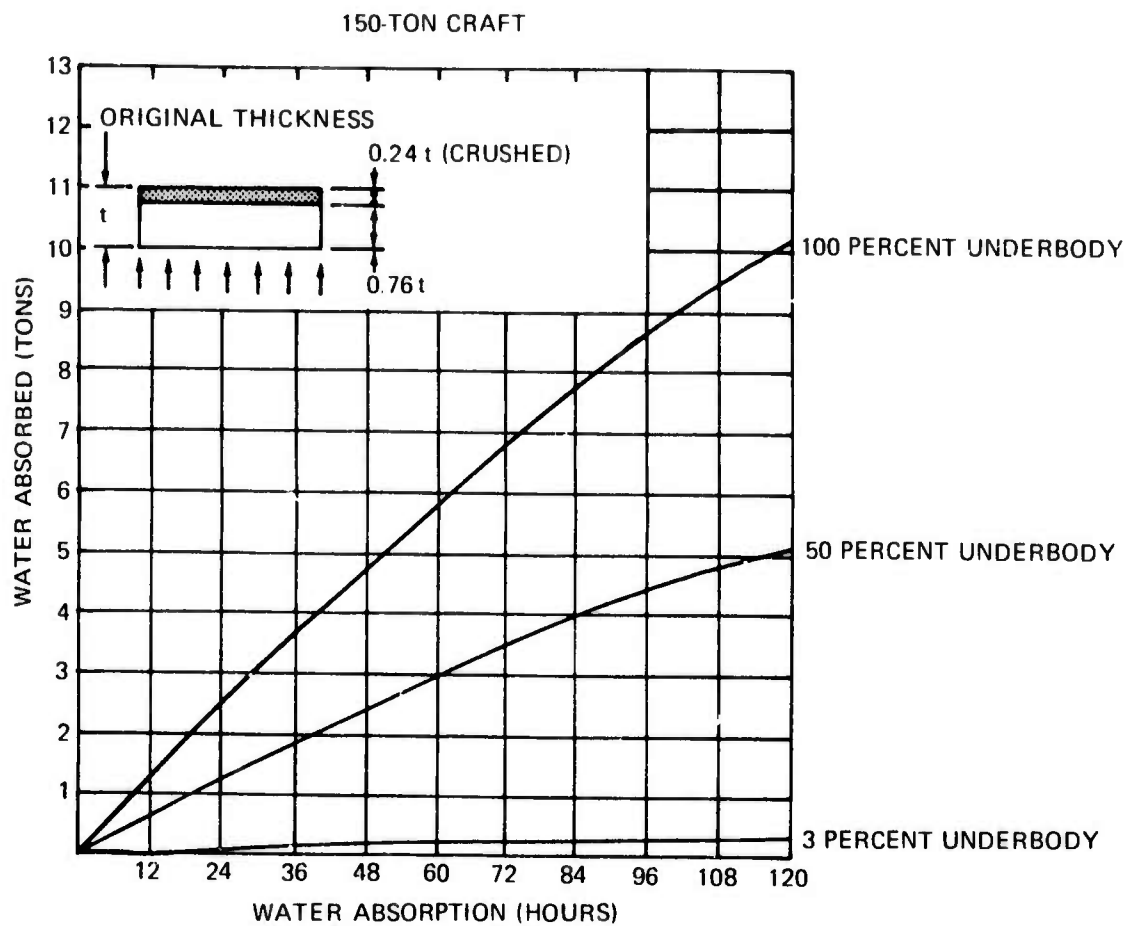
28

Figure 20 - Water Absorbed by Crushed Foam as a Function of Underbody
Area Involvement

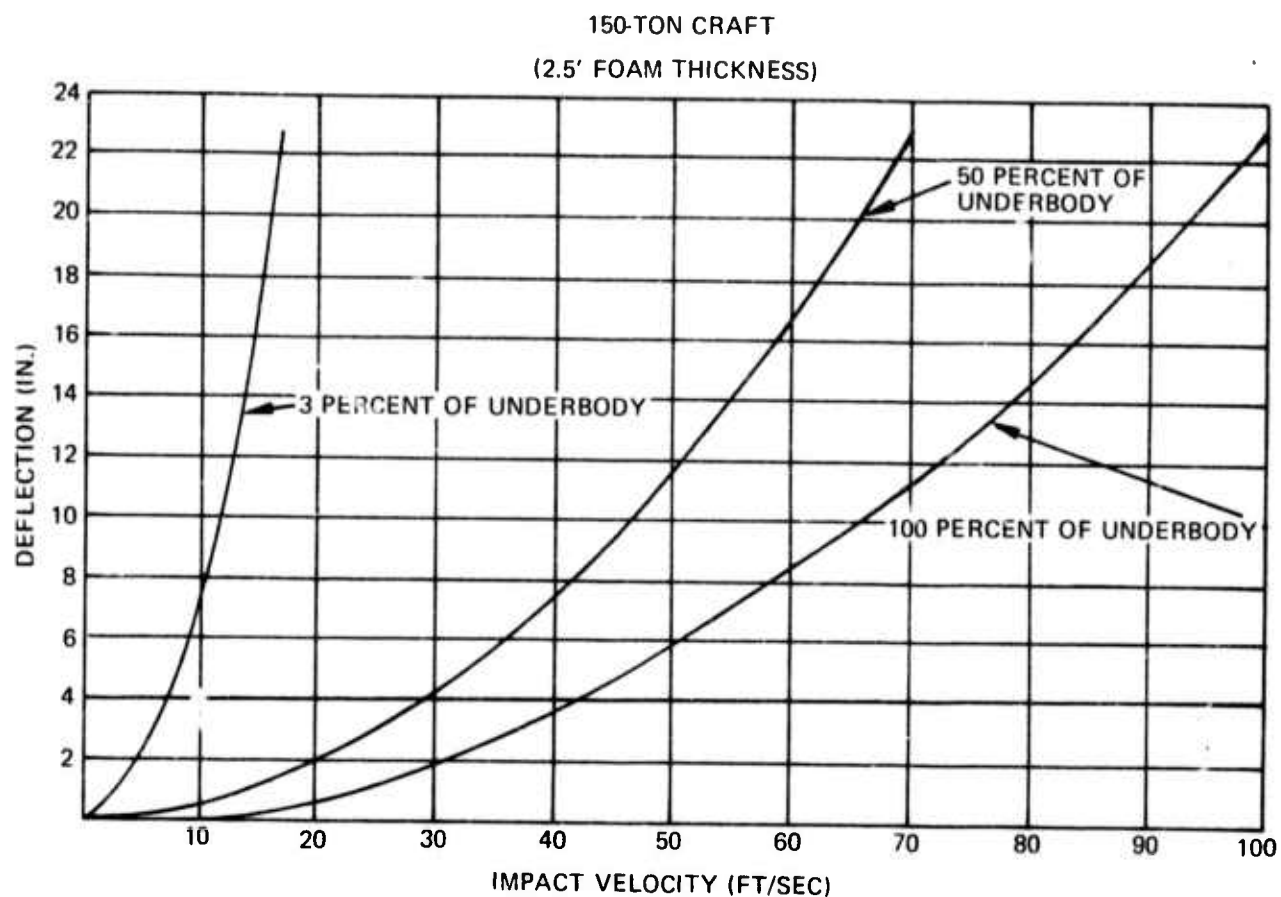150-TON CRAFT

(2.5' FOAM THICKNESS)

Figure 21 - Deflection versus Impact Velocity as a Function of
Underbody Area Involvement

area on the 150-ton craft will gain approximately 0.050, 0.115, and 0.84 percent of the total craft weight, respectively. For the same percentages of involvement and prolonged submergence (5 days), the results show respective increases of 1.91, 1.67, and 3.82 percent in the total craft weight. For the larger contact areas, this could mean a decreased operating efficiency. Furthermore, there will almost certainly be problems with the freeze/thaw cycle, which will likely cause further damage to the foam.

CONCLUSIONS

The following conclusions are based on the results of this experimental study.

1. The dynamic crushing pressure is a function of velocity, thickness, and temperature and is about 1.5 to 2.7 times the static compressive strength.

2. Cold temperatures (about -10 F) reduce the dynamic crushing pressure somewhat and slightly increase the effective thickness ratio (i.e., the ratio of the maximum foam deformation caused by a dynamic load without bottoming to its original thickness t). The net effect of the temperature on the energy-absorbing capabilities of the foam is small, however, at least for the temperatures investigated.

3. Urethane foam exhibits resilient qualities when crushed under a dynamic load that causes cell collapse. It therefore acts like a sponge and absorbs water when immersed. The added weight of water may be a serious problem in major collisions.

4. The energy-absorbing capability of low-density, closed-cell urethane foam is good if large surface areas of the foam are involved. If vertical impact is on a pinnacle or other small contact obstacle, the energy-absorbing capability of the foam is less satisfactory and underbody damage may result.

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13 ABSTRACT

The impact behavior of a low-density urethane foam was investigated experimentally, and the crushing characteristics of the rigid closed-cell foam were determined as a function of impact velocity, foam sample thickness, and temperature. The dynamic crushing strength of the material was found to be much better than its static strength. This energy-absorbing capability allows consideration of the foam as protection for the underbodies of Arctic surface effect vehicles (ASEV) against the impact of collisions.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Impact						
Energy Absorption						
Urethane Foam						
Arctic Surface Effect Vehicle						
Ice Obstacles						

1 a